# Thermal-Structural Analysis of the MacArthur Maze Collapse

Charles R. Noble
(925) 422-3057
noble9@llnl.gov

At approximately 3:45 AM on the morning of April 29, 2007, a tractor-trailer rig carrying 8,600 gallons of fuel overturned on the connector from Interstate 80 to Interstate 880 in Oakland, California. The accident resulted in an intense fuel fire that weakened the steel superstructure above it and initiated connection failures between the bridge deck and main girder, causing an approximately 50-yard long section of the connecting ramp to collapse onto the lower connector. It was determined that studying the structural collapse of the MacArthur Maze would provide the opportunity to:

1. study the methods needed to properly stimulate the themal loading on a structure from this type of event;
2. determine the predictive capability of LLNL's finite element software for progressive collapse analysis; and
3. validate this type of thermal/structural failure analysis, which would then assist in determining the threat to other critical infrastructure in the United States.

## Project Goals

The end goal of this project was to simulate progressive collapse of the MacArthur Maze connector using LLNL thermal and structural finite element simulation codes TOPAZ3D, Diablo, NIKE3D, and ParaDyn. Other goals included:

1. validating that TOPAZ3D and Diablo obtain similar results for a thermal analysis;
2. validating that NIKE3D, Diablo, and ParaDyn obtain similar results for a structural analysis; and
3. performing a fully-coupled thermal-structural analysis using Diablo in a parallel computing environment.

## Relevance to LLNL Mission

Validation of computational software for predicting progressive collapse of large structural systems is extremely difficult. The ability to perform progressive collapse simulations of critical infrastructure is important for Homeland Security applications, and therefore relevant to the mission of LLNL.

## FY2007 Accomplishments and Results

A thermal model was successfully developed for TOPAZ3D and Diablo that showed equivalent calculated temperature values within 2% at key locations in the model. Figure 1 shows the temperature distribution at one hour for a flame temperature of 1200 °C using TOPAZ3D.

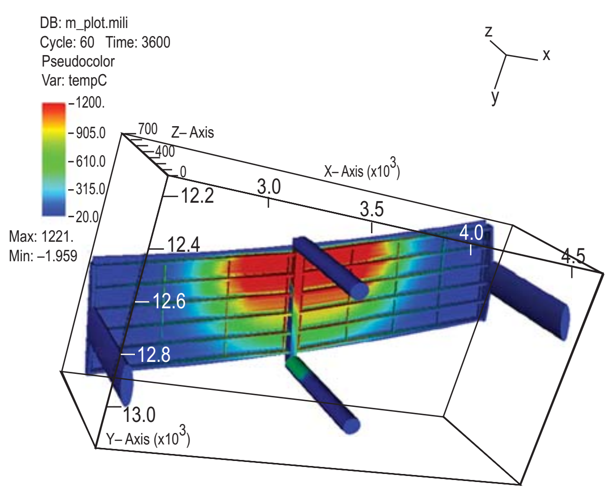


Figure 1. Simulated temperature distribution from a stationary fire at one hour using the code TOPAZ3D.

The thermal model approximated the fire as a box-shaped region for determination of heat transfer to the structure. This "flame box" extended from the underside of the concrete roadway down to sixteen feet elevation below the center of the main box girder. The lateral position, orientation, and shape of the flame box were adjusted as a function of time corresponding to video footage from the East Bay Municipal Utility District. The amount of radiative and convective transport from the flame box to a given surface facet at a given time

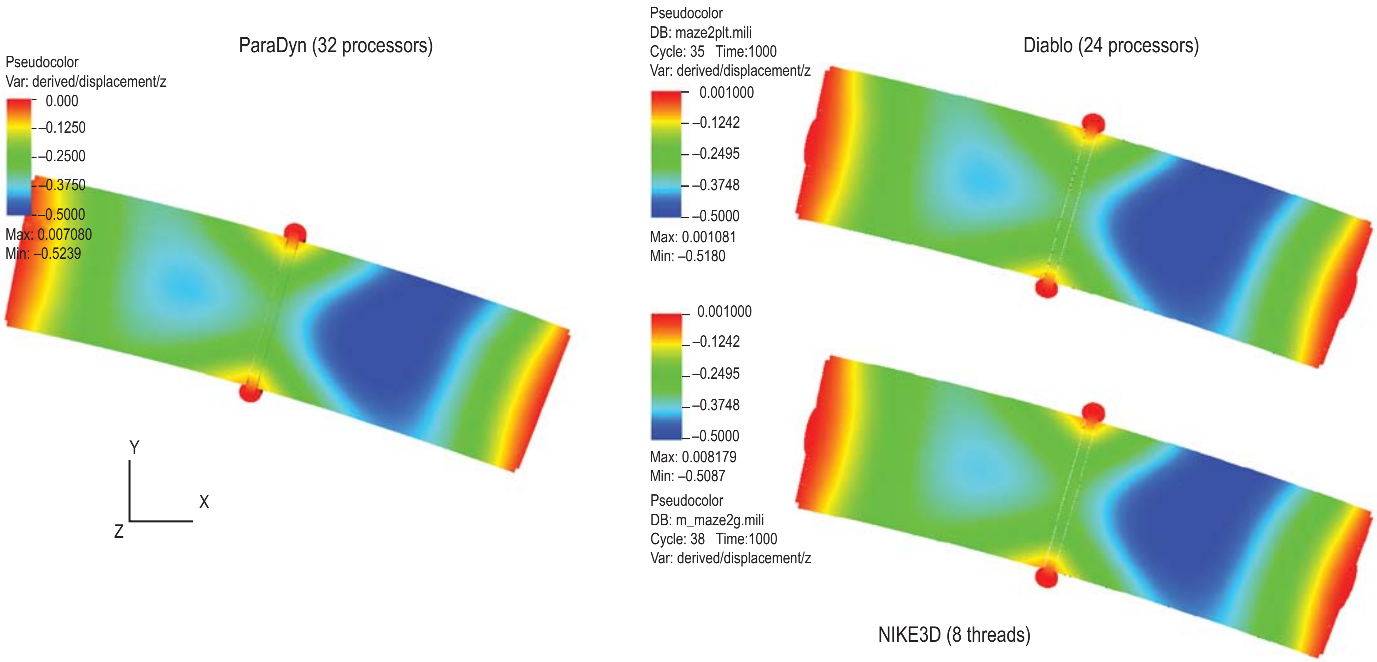


Figure 2. Overhead view of MacArthur Maze connector under pure gravity load. The three plots show all three LLNL structural codes providing the same resulting displacement. The red is 0.0 in.; the blue represents a vertical displacement of –0.5 in. For comparison, the peak CalTrans calculated displacement was –0.5 in. for the right span.

was determined based on the facet and flame box location and orientation, where radiative view factors and an applied thermal decay length for the convective gas temperature were used.

Structural models for the MacArthur Maze were developed for NIKE3D, Diablo, and ParaDyn. Both NIKE3D and ParaDyn have the ability to incorporate the thermal loads calculated within TOPAZ3D for use in the structural analysis. However, this methodology does not account for transient structural deformation effects on the calculated thermal profiles.

Diablo, on the other hand, has the ability to perform the thermal and structural analysis in a fully-coupled manner. Gravity loading was applied to the structure prior to performing the thermal-structural analysis. Figure 2 shows a displacement comparison of the model under gravity load for the LLNL structural finite element codes. Not only do all three finite element codes give similar results, but the codes predict similar vertical displacements to the calculated displacements of the California Department of Transportation (CalTrans). Figure 3 shows the simulated collapse of the MacArthur Maze connector using TOPAZ3D for the thermal loading and ParaDyn for the structural loading, assuming a flame temperature of 1200 °C.

## Related References

1. Buyukozturk, O., and F. J. Ulm, Materials and Structures, pp. 83-105, MIT Press, 2002.
2. Chen, J., and B. Young, "Experimental Investigation of Cold-Formed Steel Material at Elevated Temperatures," *Thin-Walled Structures*, **45**, pp. 96-110, 2007.
3. Outinen, J., and P. Makelainen, "Mechanical Properties of Structural Steel at Elevated Temperatures and After Cooling Down," *Fire Mater.*, **28**, pp. 237-251, 2004.
4. Takagi, J., and G. Deierlein, "Strength Design Criteria for Steel Members at Elevated Temperatures," *Journal of Constructional Steel Research*, **63**, pp. 1036-1050, 2007.


Figure 3. Simulated collapse of the MacArthur Maze connector using TOPAZ3D for the thermal loading and ParaDyn for the structural loading. (Photo courtesy of San Francisco Chronicle.)